

THE $\tau^- \rightarrow (\omega, \phi)\pi^- \nu_\tau$ DECAYS IN THE CHIRAL MODEL

K. R. Nasriddinov, B. N. Kuranov, T. A. Merkulova

Institute of Nuclear Physics, Academy of Sciences of Uzbekistan,
Ulugbek, Tashkent, 702132 Uzbekistan

The $\tau^- \rightarrow (\omega, \phi)\pi^- \nu_\tau$ decays of the τ lepton are studied using the method of phenomenological $SU(3) \times SU(3)$ chiral Lagrangians. It is shown that the obtained value for the $\tau^- \rightarrow \phi\pi^- \nu_\tau$ decay probability is very sensitive to deviations from the mixing angle. Calculated partial widths for these decays are compared with the available experimental and theoretical data.

At present the studies of the $\tau^- \rightarrow (\omega, \phi)\pi^- \nu_\tau$ decays are of great interest. These investigations could be provide evidence axial vector second class currents [1] and useful information on the $\omega - \phi$ mixing angle.

The $\tau^- \rightarrow \omega\pi^- \nu_\tau$ decay mode has been studied in the framework of the vector-meson dominance model [2], a low energy $U(3) \times U(3)$ chiral Lagrangian model [3] and, using the heavy vector-meson chiral perturbation formalism [4]. The $\tau^- \rightarrow (\omega, \phi)\pi^- \nu_\tau$ decay channels have been studied using the CVC hypothesis [5] and the vector meson dominance model [6] as well.

In this paper we study the $\tau^- \rightarrow (\omega, \phi)\pi^- \nu_\tau$ decay channels using the method of phenomenological $SU(3) \times SU(3)$ chiral Lagrangians (PCL's) [7]. Recently [8] the $\tau \rightarrow VP\nu_\tau$ decay channels of the τ lepton have been studied also using this method. In order to investigate these decay modes we have obtained the expression of weak hadron currents between pseudoscalar and vector meson states by including the gauge fields of these mesons in covariant derivatives [9]. The weak hadron currents in this way have the form

$$J_\mu^i = F_\pi g v_\mu^a \varphi^b f_{abi}, \quad (1)$$

where $F_\pi = 93$ MeV, g is the "universal" coupling constant, which is fixed

from the experimental $\rho \rightarrow \pi\pi$ decay width:

$$\frac{g^2}{4\pi} \simeq 3.2,$$

v_μ^a and φ^b represent the fields of the 1^- and 0^- mesons, respectively.

The partial widths of the $\tau^- \rightarrow (\omega, \phi)\pi^- \nu_\tau$ decay channels are equal to zero according to the obtained expression of weak hadron currents Eq.(1). Therefore these channels can be realized via effects of secondary importance. Here, we calculate the partial widths of these decay modes in the framework of the abovementioned method. Note that the hadron decays of the τ lepton up to three pseudoscalar mesons in the final state have been studied also in the framework of this method [10, 11].

In the PCL's, the weak interaction Lagrangian has the form

$$L_W = \frac{G_F}{\sqrt{2}} J_\mu^h l_\mu^+ + h.c., \quad (2)$$

where $G_F \simeq 10^{-5}/m_P^2$ is the Fermi constant,

$l_\mu = \bar{u}_l \gamma_\mu (1 + \gamma_5) u_{\nu_l}$ is the lepton current, and hadron currents have the form [7]

$$J_\mu^h = J_\mu^{1+i2} \cos \Theta_c + J_\mu^{4-i5} \sin \Theta_c,$$

where Θ_c is the Cabibbo angle, and $\rho, \rho' \dots$ meson currents are defined as

$$J_\mu^{1+i2} = \frac{m_\rho^2}{g} \rho_\mu^-.$$

The strong interaction Lagrangian of vector mesons with vector and pseudoscalar mesons has the form

$$L_s(vv\varphi) = -g_{vv\varphi} \varepsilon_{\mu\nu\alpha\beta} Sp(\partial_\mu \hat{V}_\nu \partial_\alpha \hat{V}_\beta \hat{\varphi}), \quad (3)$$

where $g_{vv\varphi} = 3g^2/16\pi^2 F_\pi$ is the coupling constant, $\hat{V}_\mu = \frac{1}{2i} \lambda_i v_\mu^i$, and $\hat{\varphi} = \frac{1}{2} \lambda_i \varphi^i$.

According to this equation the strong interaction Lagrangians of the ρ^- , ρ'^- ... mesons with (ω, ϕ) and π^- mesons, at 39° of the $\omega - \phi$ mixing angle, have the forms

$$L_S(\rho^- \rightarrow \omega\pi^-) = -\frac{i}{2}g_{vv\varphi}\varepsilon_{\mu\nu\alpha\beta}\partial_\mu\omega_\nu\partial_\alpha\rho_\beta^+\pi^-, \quad (4)$$

$$L_S(\rho^- \rightarrow \phi\pi^-) = -0.0016ig_{vv\varphi}\varepsilon_{\mu\nu\alpha\beta}\partial_\mu\phi_\nu\partial_\alpha\rho_\beta^+\pi^-. \quad (5)$$

According to the Lagrangians (2) and (4) the decay amplitude for the $\tau^- \rightarrow \omega\pi^-\nu_\tau$ decay channel has the form

$$M = \frac{G_F m_\rho^2 g_{vv\varphi} \cos\Theta_c}{\sqrt{8}g[S_1 - m_\rho^2 - i(m_\rho\Gamma_\rho)]} [\varepsilon_{\mu\nu\alpha\beta}(P_\alpha^\omega K_\mu^\rho \epsilon_\beta^\lambda(\omega)) \bar{u}_\nu \gamma_\nu (1 + \gamma_5) u_\tau], \quad (6)$$

where $\epsilon_\beta^\lambda(\omega)$ is the polarization vector of ω -meson, P_α^ω , K_μ^ρ are the 4-momenta of the ω - and ρ -mesons, respectively. Using Eq.(6) we have defined the squared matrix element of this process

$$|M|^2 = -K[m_\omega^2 m_\pi^2 (0.5(S_2 - m_\pi^2) + 0.5(S_3 - m_\omega^2)) - m_\omega^2 (0.5(S_2 - m_\pi^2))^2 - m_\pi^2 (0.5(S_3 - m_\omega^2))^2 + 0.25(S_2 - m_\pi^2)(S_3 - m_\omega^2)(S_1 - m_\pi^2 - m_\omega^2) - (0.5(S_1 - m_\pi^2 - m_\omega^2))^2 (0.5(S_2 - m_\pi^2) + 0.5(S_3 - m_\omega^2))],$$

where

$$K = \frac{2G_F^2 m_\rho^4 (3g \cos\Theta_c)^2}{(16\pi^2 F_\pi)^2 [(S_1 - m_\rho^2)^2 + (m_\rho\Gamma_\rho)^2]},$$

S_1, S_2 and S_3 are the Mandelstam variables. Note that the squared matrix element for the $\tau^- \rightarrow \phi\pi^-\nu_\tau$ decay channel can be easily obtained by replacing $m_\omega \rightarrow m_\phi$ and the corresponding K , which is defined according to the Lagrangian (5).

Using Lagrangians (2), (4), and (5) we calculated the partial width of the $\tau^- \rightarrow (\omega, \phi)\pi^-\nu_\tau$ decay channels by means of the TWIST code [12] and obtained for the first decay channel $\Gamma(\tau^- \rightarrow \omega\pi^-\nu_\tau) = 0.44 \times 10^{11} \text{sec}^{-1}$. This obtained result for the partial width is consistent (within errors) with the experimental value $\Gamma(\tau^- \rightarrow \omega\pi^-\nu_\tau) = (0.54 \pm 0.17) \times 10^{11} \text{sec}^{-1}$ [13]

and with the VMD model prediction $\Gamma(\tau^- \rightarrow \omega\pi^-\nu_\tau) = (0.42 \pm 0.19) \times 10^{11} \text{sec}^{-1}$ [6] than the prediction [3] $\Gamma(\tau^- \rightarrow \omega\pi^-\nu_\tau) = 0.31 \times 10^{11} \text{sec}^{-1}$, but it lies below the prediction by the CVC hypothesis $\Gamma(\tau^- \rightarrow \omega\pi^-\nu_\tau) = (0.73 \pm 0.10) \times 10^{11} \text{sec}^{-1}$ [5]. In these calculations we use $\omega - \phi$ mixing as

$$\begin{aligned}\omega &= V_8 \sin\Theta_V + V_0 \cos\Theta_V, \\ \phi &= V_8 \cos\Theta_V - V_0 \sin\Theta_V,\end{aligned}$$

and at the $\Theta_V = 39^\circ$ for the probability of the $\tau^- \rightarrow \phi\pi^-\nu_\tau$ decay channel we obtain

$$\Gamma(\tau^- \rightarrow \phi\pi^-\nu_\tau) = 0.38 \times 10^6 \text{s}^{-1}.$$

This obtained result is consistent with the experimental data [14] $\Gamma(\tau^- \rightarrow \phi\pi^-\nu_\tau) < (12.04 \pm 0.07) \times 10^8 \text{s}^{-1}$, but it lies below the VMD model [6] prediction $\Gamma(\tau^- \rightarrow \phi\pi^-\nu_\tau) = (0.41 \pm 0.17) \times 10^8 \text{s}^{-1}$, and almost four orders of magnitude below the upper limit obtained using the CVC hypothesis [5] $\Gamma(\tau^- \rightarrow \phi\pi^-\nu_\tau) < 0.31 \times 10^{10} \text{s}^{-1}$. And at the ideal mixing angle $\Theta_V = 35, 3^\circ$, for this decay channel we obtain $\Gamma(\tau^- \rightarrow \phi\pi^-\nu_\tau) = 1.27 \times 10^8 \text{s}^{-1}$, which is lies above the prediction [6]. We can observe that the obtained value for the $\tau^- \rightarrow \phi\pi^-\nu_\tau$ decay probability is very sensitive to deviations from the mixing angle as

$$\frac{1}{2\sqrt{3}} \cos\Theta_V - \frac{1}{2\sqrt{2}} \sin\Theta_V.$$

Therefore this decay channel could be used as ideal "source" for the $\omega - \phi$ mixing study and could be defined from the measured partial width of the $\tau^- \rightarrow \phi\pi^-\nu_\tau$ decay channel at a τ -charm factory with high accuracy. Note that the $\tau^- \rightarrow \omega\pi^-\nu_\tau$ decay probability is almost independent from the $\omega - \phi$ mixing angle (at the $\Theta_V = 39^\circ$ and $\Theta_V = 35, 3^\circ$ is equals approximately to 1/2) according to

$$\frac{1}{2\sqrt{3}} \sin\Theta_V + \frac{1}{2\sqrt{2}} \cos\Theta_V.$$

In these decays $\rho(1450)$ - and $\rho(1700)$ -vector intermediate meson state contributions have been taken into account also according to Eqs. (2), (4), and (5), which have the same flavor quantum numbers as $\rho(770)$ meson. Therefore in our calculations we used also the same g -coupling constant, as in Ref. [8], for all the $\rho(770)$ -, $\rho(1450)$ -, and $\rho(1700)$ - vector intermediate meson states which have widths of 151, 310, and 235 MeV, respectively. And in these decays contributions of the $\rho(1450)$ - and $\rho(1700)$ -vector intermediate meson states dominate those of the $\rho(770)$ ones. Note that in calculations [3, 4] contributions from these higher radial excitations have not been taken into account. And in Ref's [2, 6] these decay channels are calculated assuming only one ρ' resonance in addition to the ρ meson.

In summary, the Lagrangians (2), (4), and (5) allow us to describe of $\tau^- \rightarrow (\omega, \phi)\pi^- \nu_\tau$ decays in satisfactory agreement with the available experimental data and theoretical predictions. And, probably, taking into account corresponding coupling constants, as in Ref. [6], would allow us to describe these decays more correctly compared to these calculations.

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